A Description of the PHENIX Muon Tracking Survey System

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Abstract

The PHENIX muon tracking system will be used to accurately measure the mass of upsilon vector mesons. To ensure that the mass resolution is not degraded by the alignment of the chambers in the system, it is required that the relative alignment of three tracking stations be known to approximately 25 μm. The system that will be used to achieve this will be described including an overview of the method, the mechanical requirements placed on the components of the system, the expected placement accuracy required for the tracking chambers, and the results of a simulation of the system.

Introduction

A schematic of one arm of the PHENIX muon tracking and muon identifier systems is shown in Figure 1. It consists of three stations of cathode strip chambers which range from approximately 1.5 m in height and width to chambers which are approximately 3.5 m in height and width. The chambers are separated in z by approximately 4.5 m. Each station is comprised of four (station 1) or eight (stations 2 and 3) chambers covering 360° in phi. All chambers are mounted in a magnet which has a radial field so that the momentum of charged particles can be measured. The tracking system will be used to reconstruct upsilon vector mesons with a mass resolution of 200 MeV/c^2. To achieve this mass resolution, a spectrometer momentum resolution of better than 2% is required at the momentum of upsilon decay muons which is typically 10-30 GeV/c. With three tracking stations and three fine resolution measurement planes at each station, a chamber plane resolution of 100 μm is required. This corresponds to a station resolution of 58 μm. In order to make sure that the alignment of the chambers to each other does not contribute significantly to the momentum resolution, the *relative* alignment of the chambers to each other should be measured to 25 μm or better over the distance of 4.5 meters. It is important to note that it is only the relative alignment of the chambers that must be known to high accuracy and not the absolute positions of the chambers with respect to each other because the momentum measurement is based on measuring the displacement of a particle at the second tracking station with respect to a line drawn between the first and third tracking stations. The absolute positions of the chambers with respect to a PHENIX hall monument system must be known for tracking through the magnetic field, etc., but these measurements will need to be performed to much less accuracy as will be described below. In addition to the measurement of the relative alignment of the stations to each other, the chambers must be constructed such that the cathode strip positions are known with respect to some external chamber fiducials to 25 μm so that the internal alignment of the chambers does not contribute significantly to the station resolution.

Achieving this type of alignment measurement precision is a multi-step process which involves accurately etching the strips of the cathode strip chambers relative to the chamber frame fiducials, accurately placing alignment measuring components into mounts and then onto the chambers with respect to these strips, and then having an active alignment measurement system which measures relative alignments to better than 25 μm.

In addition to measuring the relative alignment after placing the tracking chambers in the PHENIX muon magnet, we would like to monitor the alignment in real time so that we can correct for motions of the chambers that occur in a time span that is too short to measure with real particle tracks. This might include thermal expansion and contraction of the chambers or the material that the chambers are mounted to, settling of the detector hall, etc. This requirement has lead us to an alignment measurement system that is capable of measuring the relative alignment of chambers in the time span of minutes and can take measurement points at any time.

In this paper the monitors that will be used to measure the relative alignment of the three stations of chambers with respect to each other will be described. Also, the errors that contribute to the alignment measurements, the required placement accuracies of the alignment measuring components, the method for achieving this placement accuracy, and the placement accuracy requirements for the chambers will be discussed.

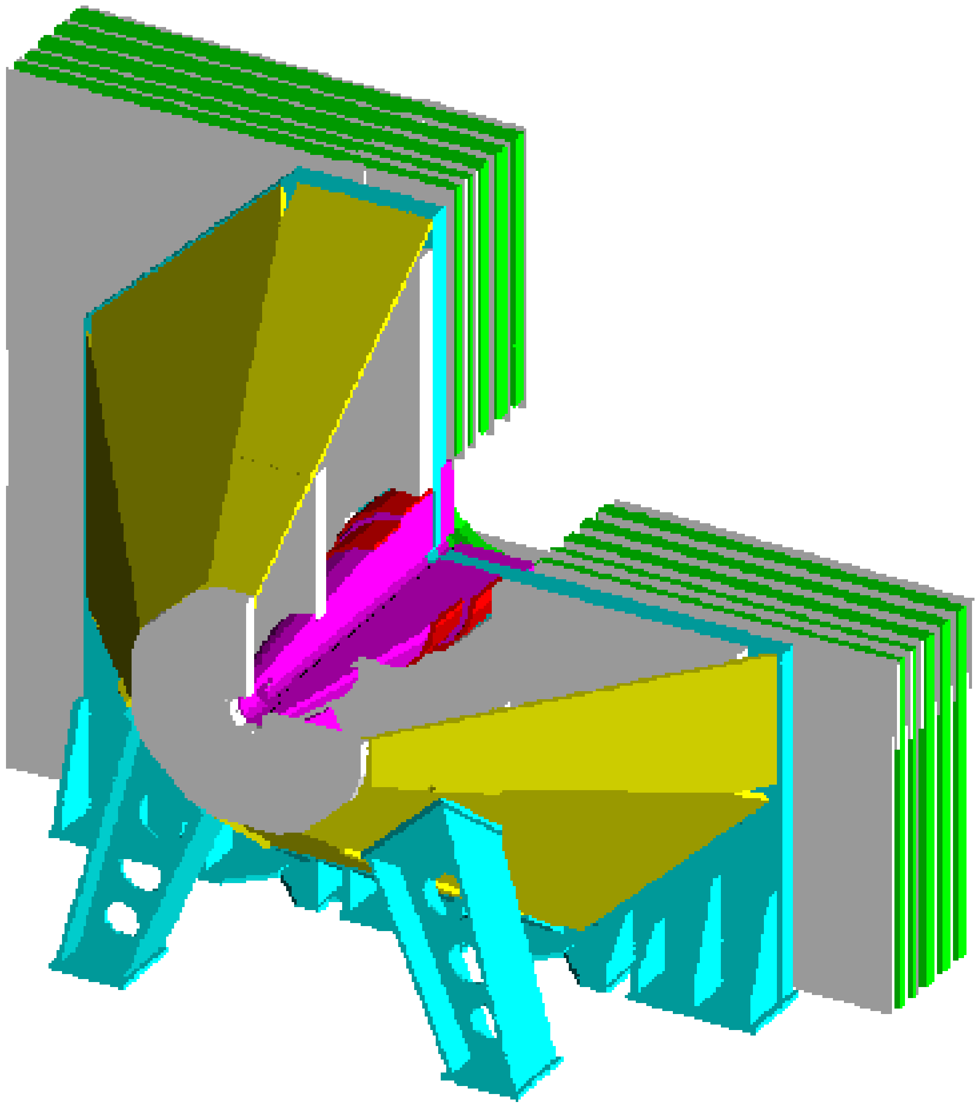

Figure 1: One arm of the PHENIX muon tracking system, showing the magnet and the three tracking stations, followed by muon identifier planes.

Alignment Requirements for the PHENIX Muon Tracking System

The alignment and survey requirements of the muon tracking system have been determined by simulating various misalignments of the system and looking at the effect of the misalignments on the reconstructed mass resolution of ϕ, J/ψ and Υ vector mesons. We have then required that the misalignments contribute negligibly to the mass resolutions. The details can be found in[1] and the resulting requirements are summarized in Table I. In the table, Internal Survey Requirements states how well the alignment of the tracking stations must be *measured* with respect to each other, Global Survey

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[1] M. L. Brooks, "Muon Alignment Requirements", Phenix-muon-95-11 (May 1996).

Requirements states how well we must *measure* the tracking station positions with respect to other systems in the PHENIX hall, and Internal Alignment Requirements states how well we must *place* the tracking stations with respect to each other at installation time.

Table I: The internal and global survey and alignment requirements of the PHENIX muon tracking system. See text for descriptions of the three requirements lists.

	x(mm)	y(mm)	z(mm)
Internal Survey Requirements:			
Station-to-Station	0.025	0.025	0.4
Global Survey Requirements:			
To Magnet:	6.0	6.0	30.0
To Vertex	1.0	1.0	5.0
North arm-to-South	1.2	1.2	5.0
To Hall Monuments	0.7	0.7	0.4
Internal Alignment Requirements:			
Station-to-Station	1.9	1.9	2.7

The table shows that our global survey requirements are rather loose. The tightest requirement is used to derive how well we must survey the tracking system to a common PHENIX hall monument system and it gives a requirement of a survey accuracy of 0.4 - 0.7 mm. However, within the tracking system we must know the *relative* alignment of the three tracking stations with respect to each other to 25 μm, for the reasons stated in the introduction, and we must place the tracking stations with respect to each other to a millimeter or two so that the alignment monitoring systems maintain lines-of-sight, as will be described below.

Measurement of the Alignment of the PHENIX Muon Tracking system

The measurement of the momentum of particles that pass through the muon tracking system is achieved by measuring the amount of deflection of the particle trajectory as it passes through the magnetic field from the first station to the last station of the system. In order to do this accurately, the absolute positions of the three tracking stations needs to be known only to the order of several millimeters, but the relative alignment of the three tracking stations to each other must be known to much less than the chamber resolution. The goal is to measure the relative alignment to 25 μm or better, but to require the initial placement of the chambers to be accurate to only a millimeter or more. Because of this, a system which has a dynamic range of a few mm, but is accurate to 25 μm over the entire range is needed. The system should also continuously monitor the alignment over time so that any changes in the relative alignment due to settling of the detector hall, thermal expansions of the chamber, etc. can be measured. To do this, a set of light source-lens-CCD systems (straightness monitors) spanning the three tracking stations as shown in Figure 2 have been chosen, which is similar to systems used[2] in L3 and proposed for the

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[2] B. Adeva, *et al*, “Test Results of the L3 Precision Muon Detector”, Nuclear Instruments and Methods in Physics Research **A289** (1990), 335-341.

GEM SSC Muon System[3]. The light sources are accurately mounted on station 1 chambers in known positions with respect to the internal cathode strips, the lenses are mounted on station 2 chambers, and the CCD cameras are mounted on station 3 chambers.

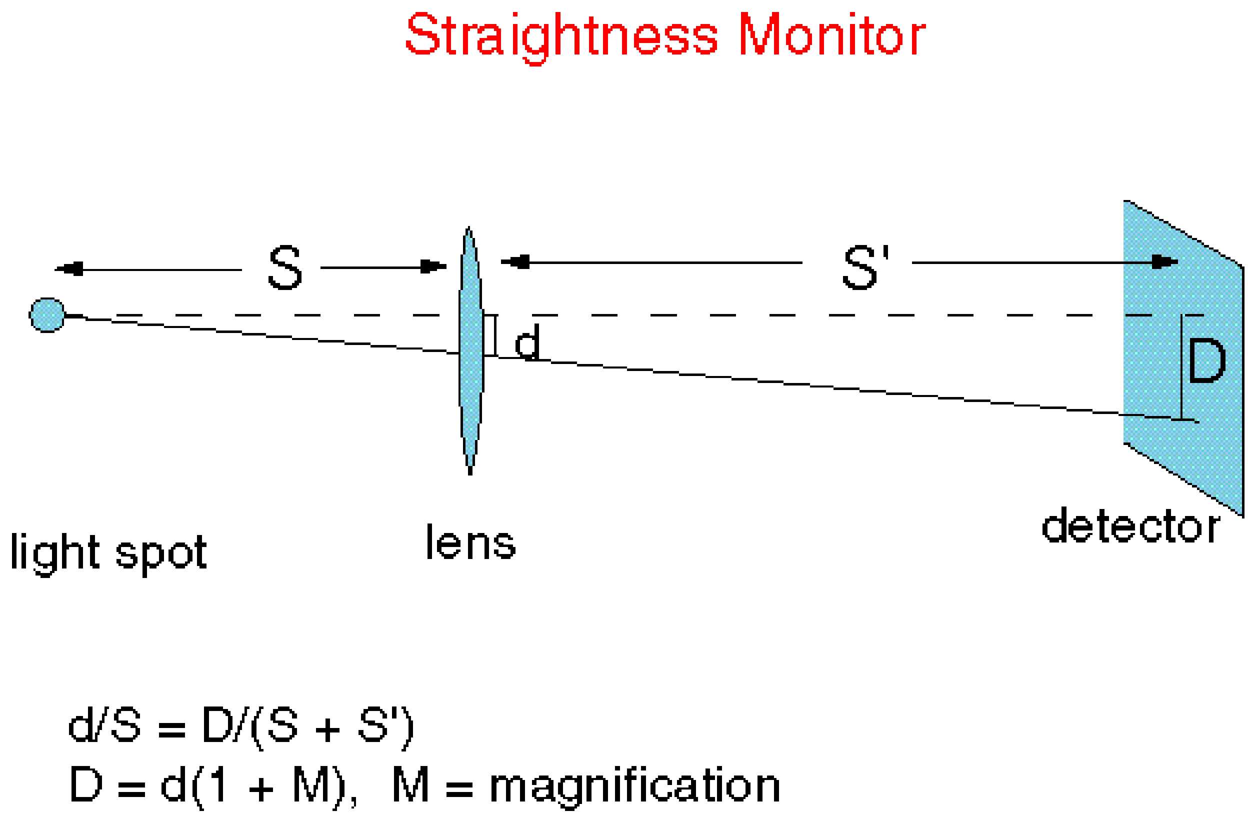

Figure 2: Schematic of straightness monitors which will be used to measure the relative alignment of the three muon stations with respect to each other. The light sources will be located on station 1 chambers, the lenses will be on station 2 chambers, and the light detectors will be on station 3 chambers.

Any deflection (d) of either station 1, station 2, or station 3 that causes the chambers to not fall in a straight line will be measured by the system (D), with a magnification factor (M) as indicated in the figure. For our system the magnification is approximately 2.5. If the deflection that is measured is always attributed to station 2 moving, then the *relative* misalignment of the three stations will be properly accounted for. Also, if several monitors are used for each rigid body (in our case, this will be an octant chamber), then the translational misalignment of the chambers as well as rotational and linear temperature expansions can be measured.

For our alignment system, we have chosen to have seven alignment monitors per chamber. Seven monitors allow us to 1) have enough monitors to correct for six degrees of freedom of motion, 2) uniformly cover a chamber which will minimize interpolation errors, 3) have a redundancy in the system in case of failure of a straightness monitor, 4) potentially have relaxed placement accuracies of the

[3] G. Mitselmakher and A. Ostapchuk, “New Approach to Muon System Alignment”, SSC Report GEM TN-92-202.

monitors because of having an over-constrained system, and 5) have the possibility of correcting for non-linear deformations of the chamber by having enough points to quadratically interpolate between points. The approximate positions of the 7 monitors on a chamber can be seen in Figure 3.

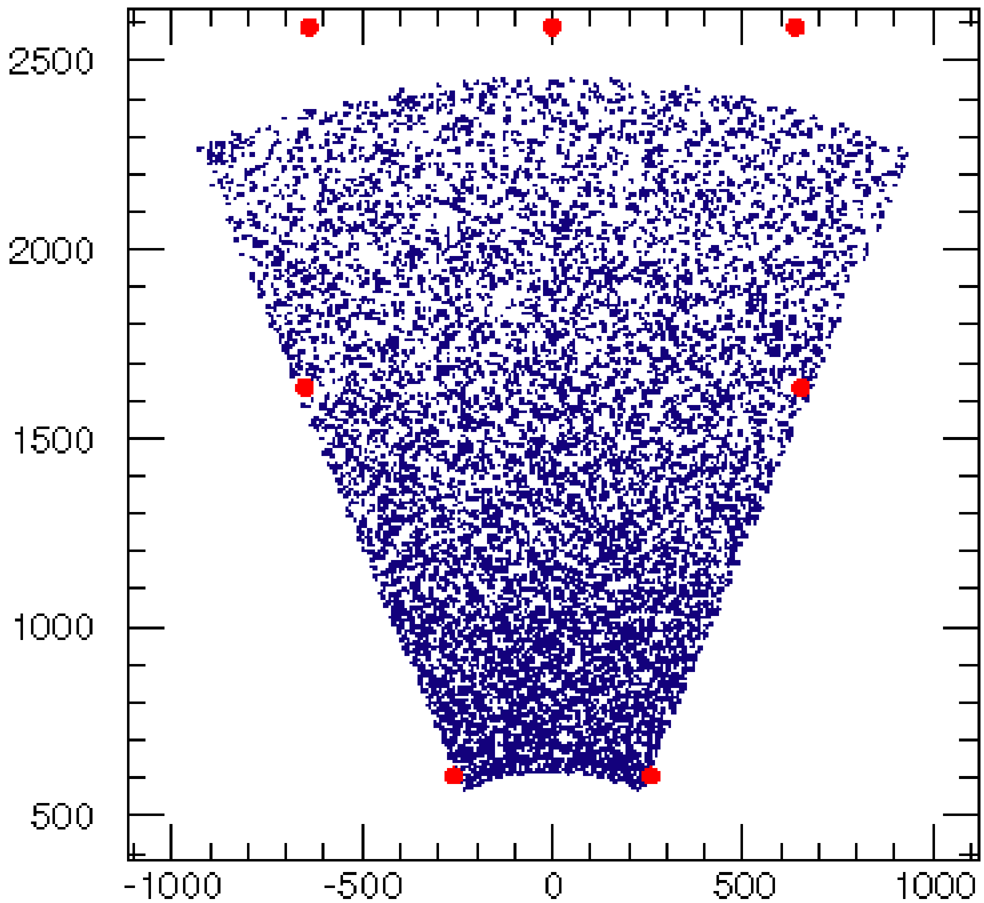

Figure 3: An outline of a station 2 chamber active area, showing the approximate seven positions where alignment monitor components will be placed.

Alignment Measurement Errors

The error in the measurement of the alignment of the chambers comes from the following:

- error in knowledge of strip position with respect to external chamber fiducials
- error in placement of the monitor components onto their mounts and error in placement of the monitor component mounts onto the chambers with respect to external chamber fiducials
- error in the straightness monitor measurement

The expected contributions to these errors and/or derived requirements are given in Table II and will be discussed below.

Table II: The errors that are expected to contribute to the measurement of the relative alignment of the three tracking stations, and the budgeted errors for each.

alignment measurement error	accuracy
strip position w.r.t. external fiducial	25 μm
light, lens, CCD w.r.t. external fiducial	25 μm
lens angular placement	1°
CCD angular placement error	0.1°
CCD measurement error	10 μm

The CCD measurement error is taken to be the intrinsic measurement resolution of a given straightness monitor. For the straightness monitor, a system which uses a white-light lamp source piped through a 100 μm diameter optical fiber, a 1 m focal length, 2.54 cm diameter lens, and a CCD camera, all mounted on an optical table has been set up. A measurement of the center of the light spot position over a weekend is shown in Figure 4. No particular care was taken to control the temperature of the electronics or the background light except that a 1 m cardboard tube was used to shield the CCD camera. As shown, a measurement precision of ±5 μm was easily achieved. Therefore, we expect to achieve the budgeted error of 10 μm listed in Table II.

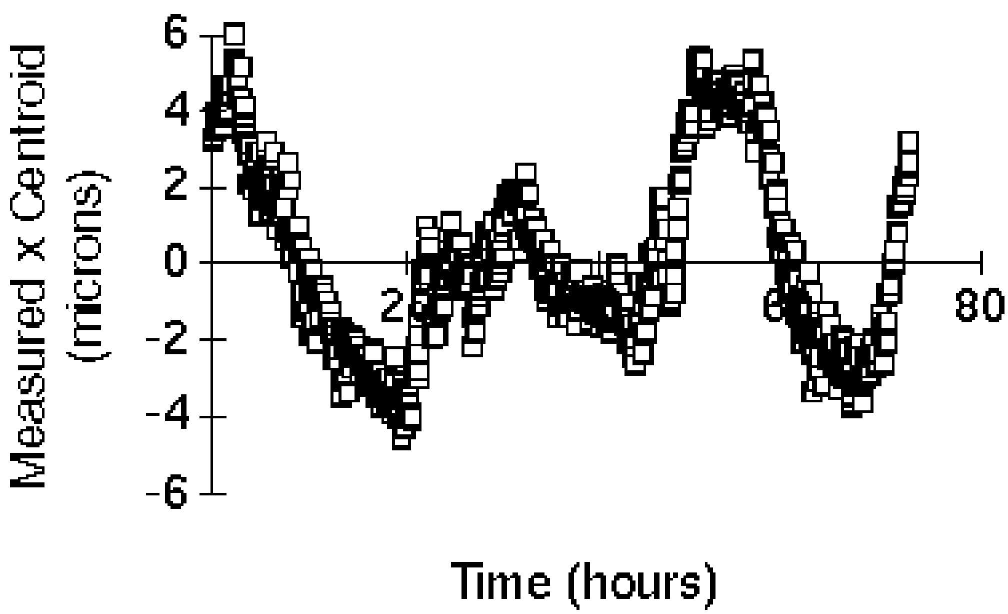

Figure 4: The measured x and y positions of a light spot over the course of a weekend. The light source, lens, and detector were in the same spacing as they will be in the muon system.

Work on prototype muon chambers has established that we are able to etch the cathode strips with respect to external alignment pins to 25 μm, so we have met the strip position error budgeted[4] in Table II.

The budgeted errors for the placement of the monitor components on the chambers have been determined by simulating the alignment system and determining what placement errors can be tolerated

[4] M. L. Brooks, D.M. Lee, W. Sondheim, "Alignment Systems for the PHENIX Muon Tracking Chambers", IEEE Transactions, June 1996 and Phenix Muon Arms Preprint 96-1 (June 1996).

and still be able to meet the goal of sagitta errors being much less than 100 μm. These simulations will be described next.

The accuracy of the positioning of the monitor components can affect the alignment measurement in several ways. These include the following: the *x-y* placement of the light source, lens, and CCD onto the chambers which directly corresponds to mis-measurement of the alignment of the three chambers; the angular placement of the lens with respect to the line of sight of the light source and the CCD because non-normal light will be displaced by refraction through the lens; the angular placement of the CCD with respect to the line of sight which will give an error in the x-y measured position in the CCD; and the magnification of the system will be different from expected if the z positions are different from their nominal values. A simulation code has been developed which takes into account all of these effects and determines the measured position of the light spot from seven monitors placed on a set of three chambers. Each chamber can be misaligned in the x, y or z direction, and rotated in θ_x, θ_y and θ_z. Straight tracks are then thrown through the chambers, the measured sagitta of each track is determined, and then the sagitta is corrected using the measured (straightness monitor) displacements and Lagrangian interpolation between measurement points. The budgeted errors listed in Table II were used, the maximum displacements that the chambers were allowed are listed in Table III, and the resulting corrected sagitta is shown in Figure 5. The maximum angular displacements may seem rather small, but for 1-3 meter chambers, this corresponds to several mm displacement at the outer edge of the chambers.

Table III. Maximum displacements of chambers in alignment system simulation.

x,y,z	3 mm
θ_x, θ_y, θ_z	0.1°

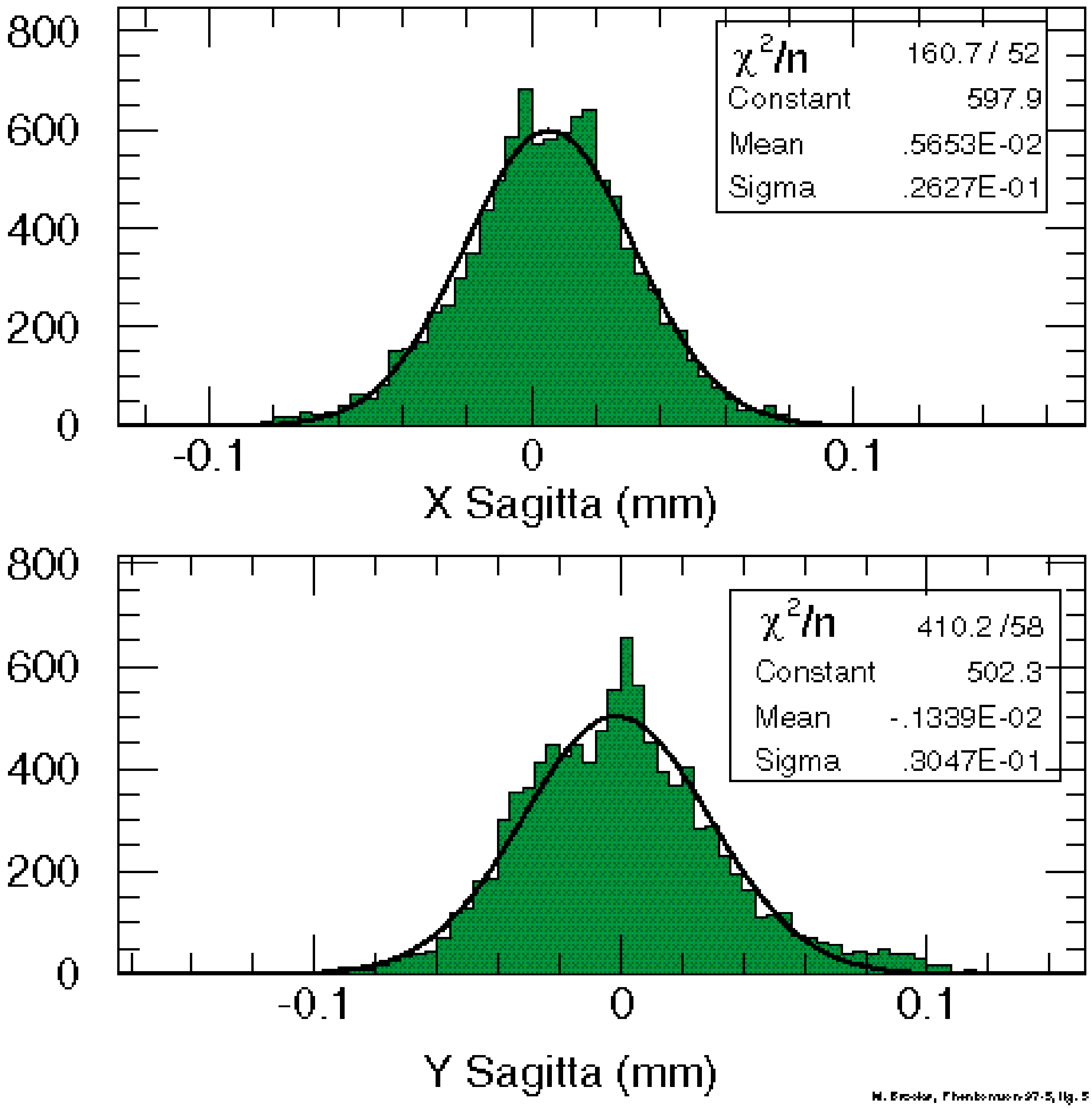

Figure 5: The corrected sagitta in the x and y direction when the errors listed below are included in the simulation.

Given the results of the simulation, sagitta measurements should be able to be corrected to well below the chamber resolution of 100 μm using seven straightness monitors per octant chamber if the mounting requirements that were used in the simulation are met.

Mounting of Alignment Components on chambers

Mounting the light sources, lenses, and CCD cameras on the chambers will be a two-step process which involves first accurately positioning the components into mounts and then pinning the mounts with the components into accurately known positions on the chambers. The result must be that the light sources, lenses, and CCDs are positioned in known places on the chambers with respect to the internal strips.

The current design concept for lens and optical fiber mounts is shown in Figure 6, mounted on top of a station 2 chamber. An aluminum mount will be machined which has the angle at which the lens must be positioned with respect to the face of the chamber machined into its front face. It also has pins that are in accurately known positions with respect to the center of the mount that will be used to put the mount on the chamber. A lens/optical fiber holder will be pinned to this mount. The holder has two set screws which allow the lens/optical fiber to be moved translationally to center the component in the mount. The centering will be achieved by pinning the mount into a calibrated straightness monitor setup on an optical table and moving the lens until the light-spot going through the lens falls exactly in the center of the CCD camera. A similar method will be used to center optical fibers and CCD cameras in their mounts, and to properly set the angle of CCD cameras (or at least calibrate them). Since the intrinsic measurement capability of a straightness monitor is better than 5 μm, we should be able to center the components to this accuracy. Therefore, the error in the placement of components on the chambers will come primarily from the errors in machining the component mounts and the alignment pin holes in the chambers.

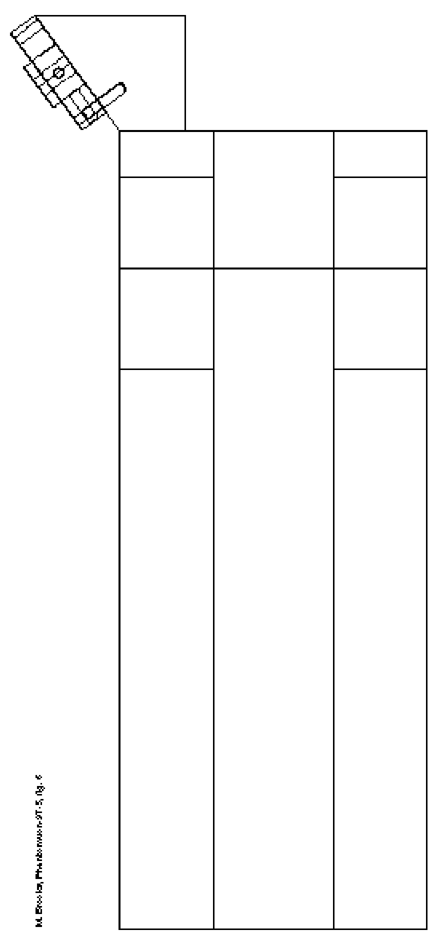

Figure 6: A picture of the conceptual design for a lens mount, mounted on top of a station 2 chamber.

Chamber placement requirements/dynamic range of alignment system

The internal alignment requirements of Table I are determined by the dynamic range of the straightness monitor systems. If the light source at station 1 never hits the lens at station 2 or the focused light from station 2 never hits the CCD camera at station 3 then the alignment monitoring system will not work. Since CCD cameras are readily available in a size of slightly less than 1x1 cm^2, it would be convenient to have the placement of the chambers fit into a system which uses 1x1 cm^2 CCD cameras. In order to make sure that the light source, lens and CCD maintain line-of-sight, the displacement of station 2 times the magnification of the straightness monitor system plus the radius of the light spot at the CCD camera must fall into the CCD active area. This means that for a given CCD size, the displacement should be no more than ±:

$$\text{displacement} = \frac{\text{CCD size}}{2.0} * \frac{1.0}{\text{mag.}} - \frac{\text{light size*mag}}{2.0}$$

$$= \text{CCD size} * (1/5) - .0125 \quad (\text{cm})$$

for our system which has a magnification of 2.5, and an expected light spot size of 100 μm. If we have a 1x1 cm^2 CCD, **the placement accuracy of the chambers must be approximately ±1.9 mm with respect to a line-of-sight between stations 1 and 3**. This means that the sum of misalignment errors that come from angular and translational displacements of the chambers must add to less than 2 mm for each station. Since the line-of-site for monitors can be at a polar angle as large as 35°, keeping a 1.9 mm x-y displacement implies that we must also **maintain a z alignment of** 1.9/tan(35°) = **2.7 mm.**

The dynamic range also determines what the requirements are for the measurement of the z positions of the stations. Since the z positions of the stations determine the magnification of the system, an error in the z position will cause an error in the magnification correction and thus an error in the measurement of the misalignment of the chambers. If the maximum displacement allowed is 2 mm and the displacement must be measured to 25 μm, then the magnification must be known to better than (100)(.025)/2.0 = 1.25%. This implies that the distances between stations should each be known to better than 1.25/√2 % which would be approximately 1.4 cm for the station 1 - station 2 distance. If we want the error from the knowledge of the magnification to be negligible compared to the other errors, we might want to specify that the z position be known to a factor of four better than this. This means that **we should know the distance from station 1 - station 2 to 3.5 mm.** Since this is larger than the alignment requirement for the stations, it adds no new survey constraints.